Heating and Cooling Applications in Winter Cities
- A Futuristic View

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ABSTRACT

A futuristic view of heating and cooling in Wintercities is presented. These systems are based on renewable energy, like solar energy for heating and snow/ice for cooling applications. The large-scale utilisation of renewable energy, or natural energy, requires seasonal energy storage. Principle solutions are discussed. Some new ideas of future developments in these fields are also presented.

BACKGROUND

Economic progress and national wealth continue to be measured in terms of Gross Domestic Product (GDP). Economic policies still aim at increasing labour productivity and production volume. Many factors that constitute real wealth have, however, not increased - or are even declining - in industrialised countries since mid 70ies. Ecological disruption is increasing, as are global natural resource consumption and population. Current environmental and social policies have not been able to stop this trend. As a consequence, we are losing natural capital at increasing speed, and we are losing the freedom to shape the future of humanity. Before long, many more resources will have to be invested in survival strategies. Obviously, these problems must be addressed urgently. [WWW, Faktor10].

As a result of the Rio Conference, 1992, and the following discussion the term “Factor 10” was internationally established. The meaning of Factor 10 is that the industrialised countries have to reduce its resource consumption by a factor of ten within 30-50 years in order to achieve a sustainable global environment

Factor 10 is easy to comprehend in energy systems; it simply means that we have to reduce our prime energy use with a factor of ten. The most efficient way to do so is probably energy conservation and implementation of renewable energy.

To reach Factor 10 target our future energy system must be based on renewable energy i.e. solar energy one way or the other.
Renewable Energy

The most obvious renewable energy source is solar radiation, which can be directly transformed to electricity or hot water. Solar energy also occurs as wind energy, wave energy, and as thermal energy passively stored in air, water, or in the ground. Solar energy is also stored in plants and trees. Renewable energy is defined by its time of renewal. So, bio-fuel is a renewable energy but oil is not because it takes such a long time for its renewal. Because of low intensity or absence of solar energy snow and ice are accumulated during the winter. This type of natural cold storage is also a type of renewable energy or rather a shortage of heat that can be used in cooling applications.

Energy Storage

In most climates there is a time difference between supply and demand of renewable energy. This mismatch can be solved by energy storage. There are many technologies developed for short-term and long-term storage (Nordell, B. Large-scale Thermal Energy Storage, WinterCities’2000)

The only valid reason for energy storage in a market economy (like it or not) is that it is more cost effective to store energy from one time to another, than to produce it later when needed. This implies that the price of energy must be lower when injected than its value when extracted. The price difference must be big enough to cover the cost of investment, maintenance, operation, and energy losses. Today, there are many economically feasible energy storage applications.

ENERGY CONSERVATION

Future Energy demand

Energy conservation is an ongoing process in modern society. Today each new appliance is more energy efficient than the replaced one. At the Swedish national energy meeting, Energitinget 1999, an estimation of our energy demand in 2050 was presented (G. Hovsenius 1999). In this prognosis a 2% annual increase in GDP was assumed, which means that our GDP at that time will be about 2.5 times greater than present GDP. With this assumption the Swedish energy demand would be reduced to half of our present energy demand. This means a 1% annual reduction in energy consumption. The study did not include transportation and no major breakthrough was assumed in the energy production or distribution system.

It is hard to foresee the future but it is reasonable to believe that our future energy demand will be considerably lower than today’s. If necessary, for environmental or economical reasons, it would be possible to speed-up the transformation of our energy systems from conventional to renewable. Then renewable energy of today would be conventional in the year of 2050.
FUTURE ENERGY GENERATION

Future Electricity Production

In this paper future electricity generation is only briefly discussed. From a Swedish view it is of importance since we have decided in a referendum to shut down our 12 nuclear power reactors. This means that about 65 TWh of electricity consumption has to be replaced one way or the other. One easy part to replace is heating system using electricity (40 TWh), which easily but not cheaply can be replaced by other types of heat production.

There is a potential of 15 TWh of new hydropower in Sweden but this is not likely to be exploited. Wind turbines have a better chance and the Swedish Energy Office has a target of 15-20 TWh generated by wind turbines in the mountain areas and in coastal areas in the future. Biofuels in co-generation would produce the rest of necessary electricity to fill up the gap after the shut down of the nuclear power production.

In the long run solar cells (photovoltaic cells) will probably become much cheaper and economically feasible which they are far from today. The consumer price for a 100 W solar cell is about 3000 SEK but is expected to be considerably lower in the future.

There is a new interesting development on thermophotovoltaics (TPV). TPV is the conversion of radiation energy from a source with a lower temperature than the sun’s to electricity with the help of photovoltaic cells (solar cells). The idea of the project is to develop a system for the production of electricity and heat from refined biofuel with TPV techniques. A feeding device for wood powder has been constructed and a prototype burner that has a flame temperature over 1400 K (more than 1100 C) has been built. [http://www.du.se/ekos/serc/research/tpv1.html and L. Broman, 1999].

Measurements showed that the TPV delivered 6 W/cm², which corresponds to 60 kW/m². This is about 600 times more than a normal solar cell. This is not yet a commercial product but it is believed that the feasibility of this very promising technique for medium-scale electricity production will be proven within five years.

Future Heating and Cooling System

It is a great task to convert our energy system for space heating from conventional energy sources to renewable energy. Today almost 40 TWh of the Swedish electricity consumption (approximately 130 TWh) is used for direct space heating.

There are some key issues to consider in transforming our heating and cooling system from our conventional energy sources to renewable energy:

- Type of heat distribution system – water as a heat carrier
- Distribution temperature – low temperature
- Thermal Energy Storage Systems – seasonal storage
Type of heat distribution system

There are some political incentives to change from direct electrical heating to different alternatives. The first step is to install a new heat distribution system. Radiators connected a hot water pipe system is the most attractive alternative for Sweden while air as a heat carrier is uncommon. First of all by changing the heat distribution system to hot water radiators is encouraged. This means increased flexibility when considering the energy source.

Distribution Temperature

The temperature of the distributed water should deviate as little as possible from the desired room temperature, maybe 30-35°C for heating and 10-15°C for cooling. This means that low quality heat could be used for heating and low quality cold for cooling. This would from an energy point of view be excellent but there is also a cost problem involved.

In new buildings the floor-heating systems are very common throughout Europe. In-the-floor-heating is, however, too expensive (500 SEK/m²) to be installed in old buildings. There is an interesting research and development at LTU with the aim of economically feasible low-temperature radiators. To avoid too large radiator area a fan is used to improve the heat transfer and the convection of heat into the room. Such radiators, originally meant to replace electric radiators for heating would also used for space cooling.

When heat pumps are used to produce the required heat, the low temperature distribution system is more efficient since it increases the COP of the heat pump. For solar heat the advantage is that solar collectors are more efficient when heat is delivered at lower temperature.

Seasonal Heat Storage

The borehole heat store has the greatest potential and the most generally applicable system for seasonal storage of thermal energy. There are several thousand systems in operation even if only a few are used for high temperature storage. [Nordell, B. Large-Scale Thermal Energy Storage, WinterCities 2000].

In the borehole system the injected heat is heating the bedrock volume to a temperature of 70-90°C. The boreholes are the heat exchangers of the system. The store is not thermally insulated but the huge volume of the store 100,000 to 1000,000 m³ of rock reduces the heat loss. In a high temperature store constructed in granite, the heat loss from the store varies with size from about 40% (100,000 m³) to 10% (1000,000 m³). If a low-temperature heat distribution system is used on the use side the temperature of the store varies from e.g. 80°C to 30°C during the year. This means that about 30 kWh is stored per m³ of the rock volume. In this type of system the heat storage cost is less than 0.10 SEK/kWh including costs of capital, maintenance, heat loss and operation.
Does solar heating have a future? No doubt! Already in 1985 three were plans to build a solar system for heating of a whole community, Kungälv, on the Swedish West Coast. At that time it was found that the cost of solar heating would be about 50% higher than that of conventional heating. These 50% were too high for the project to be realised but what does these 50% really mean? The normal heating cost of a Swedish apartment or single-family house is about 10% of the rent. So 50% extra heating cost would mean a 5% rent increase in 1985. Since then the energy cost has been increasing while solar collectors and seasonal storage systems have become more efficient and less expensive. Today, large-scale solar systems can be built at a lower cost than conventional. So far this is only possible in new areas that are initially constructed for low temperature heating.

The heating demand should not be further reduced. Considerable efforts and money are put into the development of ventilation systems with heat recovery. In my opinion this is the wrong way and is partly the reason for the sick building disease. We should not go this way – it is much better to waste some renewable energy and save the money from heat recovery and minimised ventilation.

The solar collector system must be considerably cheaper than today to replace conventional heating. We should reach about 500 SEK/m² for the whole system (incl. installation, pipes, pumps etc) within some years. This requires industrial production of
solar collectors. There are still to many small-scale manufacturers of solar collectors but from what I understand a change to more large-scale production has started.

The easiest and cheapest way to achieve direct heating from a seasonal storage is to store the heat at high temperature and to use it at low temperature. This means that some kind of low temperature heat distribution system has to be used. Since the heat losses are very much depending on the size of the storage volume it is not economically feasible today to construct heat stores for direct heating below the size of 1000 MWh, that is about the heat demand of 100 single-family houses. Today such systems require a heat demand of about 2500 MWh to be fully competitive to conventional heating systems.

The easiest way to transfer heat at low temperature is by convection of air, which speaks for an air-based heat distribution system. Such systems are common in warmer climates but uncommon in Sweden. In more northern climates people prefer to have water as the heat carrier and water radiators have the advantage of the high storage capacity in the water system.

A state-of-the-art system with seasonally stored solar heat is under construction north of Stockholm, see Figure 1 and [Gehlin, S.Heat Storage Applications, Wintercities 2000]. The only disadvantage for that system is that the heat demand is too low (approximately 1000 MWh) to show a very good operation. For a three times bigger heat demand this system would be considerably cheaper than conventional. So, this is a system for blocks of houses or residential areas.

For heating of individual single-family houses, where the houses are located too distant from each other for a centralised local heat distribution system, it is not possible to use the Anneberg solution.

In such cases the future will probably give us individual solutions for production of both electricity and heat. There are several systems for electricity production like
wind turbines, solar panels, and the main problem is the very expensive systems for electrical energy storage. Much research is going on in this field, in batteries and fly-wheels, but before these systems are economically feasible in this scale it is more likely that the PTV technology has been developed to solve this problem. The PTV research at the Solar Energy Research Centre at the University of Dalarna, Sweden, focus on systems that produce 1-10 kW electricity in biofuel furnaces. The idea of such systems is that the biofuel furnace delivers 90% heat and 10% electricity. Also with this mix there is a problem of mismatch in demand of heat and electricity. During the summer there will be some excess heat and during the winter maybe the heat demand is higher than the demand of electricity. So, also in this case there is a need for electrical energy storage but on another time scale. In this case diurnal storage of electricity would be enough. In this type of system it would be necessary to have a small hot water accumulator as well.

Future Cooling System

We foresee an increasing number of snow and ice storage systems in the future. It is truly a renewable “energy” in Wintercities. The extraordinary advantage of snow storage is that it has no limit in extraction power. Another advantage is that such storage systems can be constructed in both small and large scales. There are several seasonal snow/ice storage systems in e.g. Japan and Canada and only one in a larger scale in Sweden (Skogsberg, K. Wintercities 2000).

Large-scale snow storage will be constructed underground in rock caverns connected to District Cooling nets. We also expect several of these systems to be built also for industrial cooling. [Johansson, P. Snow Storage in Rock Cavern. Wintercities 2000]

There are many good reasons for snow storage:

- The big snow storage volumes require big land areas, which are expensive in urban areas where the major cold demand occurs.
- When the store is also used as a snow deposit the snow is most commonly removed from streets in the city. A nearby deposit reduces the cost of snow handling and transportation.
- The “energy loss” is only a few percentage of the storage capacity when the store is located underground.
- The pollution of urban snow is gathered in the cavern, which means that the meltwater easily can be analysed and treated if necessary.
- In spite of the very expensive construction cost the rock cavern snow storage is cost effective with a very short payoff time.
- It is possible to construct rock cavern in volume of several 100,000 m\(^3\). It is also possible to locate the rock caverns at different locations along the DC net.
Snow storage systems can also be constructed in a smaller scale, i.e. snow volumes from 10 to a few 1000 m$^3$. In this case the snow storage must be thermally insulated.

One example of a medium size store is the snow deposit storage at the Region Hospital at Sundsvall. This storage system with a snow volume of 30,000 m$^3$ has a capacity of about 1000 MWh with a maximum peak of 1500 kW. There are several ongoing pre-studies at LTU on snow storage systems in the range 5000 to 100,000 m$^3$. In all these cases on-ground located storages are planned. There is still no example of large-scale rock cavern snow storage.

**CONCLUDING REMARKS**

- ATES systems are feasible when the geological conditions are favourable. ATES is for large-scale cooling or heating. Still it is used for both short-term and seasonal cold and heat storage. ATES is a standard option in some countries.
- BTES is the most general type of UTES system. It is feasible in a very small scale and also in large scale. The soil cover should however not be too deep. BTES is most efficient when the task is to load and unload a base load of thermal energy. Because of the pipe installations it is possible operate at below freezing degrees.
- A combination of CTES and PCM, i.e. seasonal storage of ice and snow in a rock cavern for district cooling seems to be very promising application.
- The most important external factor for efficient UTES systems is that the temperature requirement for space heating is low, about 35°C and that the temperature requirement for cooling is about 15°C, i.e. a temperature difference of 10°C.
- The most favourable UTES applications are high temperature storage with low temperature applications without heat pumps.
- The long-term aim of storing solar heat from the summer for space heating during the winter does not seem to be far away. The Anneberg project was the first Swedish solar energy - seasonal storage project that showed similar cost for both the solar system and best conventional alternative.
- International Energy Agency results in efficient international collaboration and technology transfer. There are several ongoing projects on renewable energy and energy storage.
- The newly started Underground Thermal Storage and Utilisation - An International Peer Review Journal on Energy Conservation - has the potential to become an important forum for scientific and technical UTES information.

UTES conserves energy and improves the environment. There are many applications found in e.g. the building, industrial, agricultural and aqua-culture sectors. One big advantage for the widespread use of UTES is that local entrepreneurs are able to carry out the construction work (for BTES in particular). It should be utilised in many more countries throughout the world. Renewable energy has a great potential. Our future energy system must be based on renewable energy, an energy system in pace with Nature – without it there is no future. The key to success is international collaboration, then UTES and renewable energy will make the future come sooner.
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